Virtual Access Hydraulic Experiment for System Dynamics and Controls Education

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ABSTRACT

A Virtual Access Laboratory (VAL) for undergraduates is currently being built at Georgia Tech. This laboratory will house a three degree of freedom, hydraulically actuated device resembling a fork lift truck. Experiments with the hydraulic equipment can be run remotely via the Internet. Such an experimental apparatus will give students exposure to hydraulics, technology that is used expansively in industry, yet lightly treated in most U.S. undergraduate engineering curricula. The software responsible for providing the user interface and controlling the manipulator is comprised of both client and server programs that communicate via the Internet. The client code is written in Java and features a Graphical User Interface to provide a user-friendly environment for students. Code for the server is written in C++ to run on Windows NT with Hyperkernel for deterministic real-time control. This code will offer the students the ability to run experiments such as system identification, PID control, and trajectory planning. A camera monitors the system and provides students with visual data.

1. INTRODUCTION

Systems Dynamics and Control is a required undergraduate course in the Georgia Tech Mechanical Engineering curriculum taken by about 300 students per year. Students are expected to model dynamic systems from multiple energy domains (mechanical, electrical, hydraulic, and thermal) and design controls for them. They build on their experiences in dynamics, instrumentation laboratory, computer applications, and mathematics. Many concepts from diverse prerequisites are integrated into the course. The course as previously offered was deemed by students to be difficult and was often criticized for the lack of connection to applications or even realistic physical examples. Efforts to improve in this respect have included multimedia presentations, in class demonstrations, extensive access to simulations, and videotapes of applications. Access to hardware for hands-on experimentation is difficult due to time limitations and financial constraints even with the simplest systems and impossible with the complete range of the systems covered in the course. The students have had access to simple electric motor control in their laboratory courses but a more representative range of control systems is needed. The opportunities for ME graduates in fields applying control and system dynamics (e.g. mechatronics and manufacturing) is rapidly increasing and provides further incentive for enhancing skills in this area.

An undergraduate laboratory is under construction in which real systems are controlled and real experiments conducted remotely by students using the Internet in their dorm rooms or elsewhere. The 24 hr/day virtual access has several attractive educational features such as coupling laboratory experience with homework and reading, providing access to the real (not simulated) physics, reducing problems associated with laboratory space and scheduling, and possibly eliminating the need for multiple sets of laboratory stations. The ME course in System Dynamics and Controls is the type of course in which students will benefit considerably from the new internet technology because they could see control theory working within real systems. This laboratory is also a natural way to extend the exposure to mechatronic systems since only with this technology is this hardware access possible. Hydraulic systems are especially suitable for the virtual approach since realistic systems are expensive and must be used to their full extent.

2. HARDWARE

In order to accomplish the project objectives, a three-degree of freedom hydraulically actuated manipulator was designed. The manipulator is constructed to functionally resemble a fork lift truck (FLT), therefore making the laboratory experience closely related to familiar real-world systems. The manipulator was designed to have a maximum payload of 250 pounds. The use of hydraulic actuators allows loads of this magnitude to be handled easily.

Fig 1 shows a simple schematic of the manipulator and indicates the relevant components. Although the manipulator design allows for three degrees of freedom, the hydraulic cylinder responsible for actuating the tilt motion of the mast has been replaced with a fixed link. This replacement constrains the manipulator to two degrees of freedom within the planar workspace.

2.1 Mechanical Structure and Operation

The two degrees of freedom utilized will be linear motion along the horizontal axis and linear motion along the mast. When the angle between these two directions of motion is set to 90 degrees the manipulator behaves like a Cartesian coordinate robot.

Drive motion, the motion in the horizontal direction, is constrained by a pair of linear bearings and a linear guide rail. The length of the linear guide rail restricts horizontal travel to 48 inches. The linear motion along the mast, referred to as lift motion, is constrained by a series of guide rollers and tracks. This movement is also limited to 48 inches of travel. Therefore, in the cartesian configuration the manipulator workspace is a 48 inches x 48 inches square within the vertical plane of operation.

Fig 2 shows a three-dimensional rendering of the hydraulic manipulator from the back. In an attempt to emulate a real FLT the mast of the manipulator operates with a simplex mast design. The simplex mast design allows a single hydraulic cylinder to displace the carriage twice the distance that the cylinder displaces. The motion multiplication is a result of a chain and idler pulley system within the mast.

2.2 Hydraulic System

Hydraulic power was chosen because this widely used technology has received very little attention in most undergraduate engineering curricula in the United States. The hydraulic system operating this manipulator provides an example of typical hydraulic components used in a motion control application.

The fluid power source is a hydraulic power unit consisting of an electric motor, a variable displacement piston pump, a fluid reservoir, and associated peripheral equipment. The unit operates at 1000 psi and is capable of providing 15.6 gallons per minute of fluid flow.

Fig 3 shows a hydraulic schematic for the manipulator. This figure will supplement the following discussion of the hydraulic system. Electrohydraulic servo valves control fluid power delivery to each of the actuators. The servo valves selected are four-way valves and use two-stage operation with mechanical force feedback. In order to produce highly linear flow-gain characteristics (the relationship between valve spool displacement and load flow of the hydraulic fluid) the valves have critical centers. A critical center valve has a spool land width that is identical to the port width in the valve body. The linear flow-gain characteristic is beneficial in motion control applications.

While servo valves are used in many industrial applications, it is not the typical valve used in FLT designs. The less expensive manual valves used in FLT designs would not be feasible for use with the computer control used in the Virtual Access Laboratory.

A double-acting, single-rod hydraulic cylinder with a 2" bore and a 1.375" rod produces lift actuation. At 1000 psi this actuator can generate 3140 pounds of force. Drive motion is provided by a hydraulic motor with a displacement of 17.9 cubic inches per revolution. This motor is capable of a maximum angular velocity of 63 rpm and a maximum torque of 1072 in-lbs of torque. Angular motion is transformed into linear motion by mounting a wheel and tire combination onto the motor output shaft. The tire drive system will simulate the drive operation of an FLT, thereby increasing student experience with real-world systems.

2.3 Sensors and Data Acquisition System

Data acquisition and sensor integration are critical for this application. The sensor data will be used in controlling the system and ensuring that it remains within a specified safe operating range. In addition, all information collected from the sensors will be displayed on the client side of operation and saved in a data file for later analysis. The manipulator is instrumented with three feedback sensors: a linear displacement transducer, a rotary encoder, and a load cell. All sensors were selected to give appropriate resolution and accuracy for this manipulator.

The linear displacement transducer is responsible for measuring displacement of the hydraulic cylinder that actuates the lift motion. The transducer uses non-contact, magnetostrictive sensing technology to determine absolute position. In order to conserve space and simplify operation, the transducer is mounted inside the cylinder and is concentric with the axis of piston motion.

Displacement of the manipulator in the drive direction is measured by transforming the linear motion into rotational motion and measuring this quantity with a rotary encoder.

The load cell uses strain gage circuitry to measure forces generated by the hydraulic cylinder. Force data is used to perform system identification. The force data can also be monitored to determine lifting force on a payload and to ensure safe operation ranges.

The output signals from the sensors are transmitted through the appropriate amplifiers and filters and sent to the data acquisition board. The data acquisition board is housed within the VAL server computer. Fig 4 shows a schematic representation of the input and output signals used during manipulator operation.

A digital camera and a microphone that monitor the system at all times obtain some of the most interesting data. The camera has tilt and pan capabilities that are remotely controlled by the client side of the experiment.

3. SOFTWARE

There exists two main software components to the Virtual Access Laboratory (VAL), namely the client and server programs. The client program will serve as the student's interface to the experiment. Access to the program will be time restricted. The server program will be run locally at the hardware site. These programs will be able to communicate with each other via Georgia Tech's campus network or the Internet.

3.1 Client Software and Web Access

Previous work done by Georgia Tech students to control a manipulator using the Internet used the Java programming language for the client.[1] Using Java facilitates writing a user-friendly client program that is operational from a variety of platforms. For this experiment, the client-side software is a Java applet. The code includes control over experimental parameters and camera motion.
Applets are similar to applications, but are run from a Web page. This applet will provide the user with a Graphical User Interface (GUI). On the GUI, a variety of buttons and check boxes are available for the student. The functions of these buttons and check boxes will include options such as selecting which experiment they wish to run, what type of input they will provide, and the desired compensator gain values for a PID controller.

Access to the client program, and time slot reservations, will be done on the Internet via the World Wide Web. WebCT [2], a product providing tools for Web page support for instruction, will support the reservation of access times and will limit access to the appropriate times. Using WebCT, only students enrolled in the class will be granted access to the class homepage; furthermore only students with the appropriate reservations will be allowed access to the Internet server containing the client applet. The applet is served from the same computer that runs the actual experiment. This is necessary due to security restrictions that are inherent to applets that forbid socket connections to Internet sites other than the one that served the Web page that includes the applet. Applets are also incapable of performing read/write operations to the user's computer. Access to a file containing the experimental data will be granted to the user when the experiment is complete. Once the applet is accessed students must establish a socket connection to the server, and run the experiment. The server software will close this socket connection after the student's allotted time has expired, if the student has not already done so. A listing of the necessary steps involved in completing an experiment and the computer that acts as the Internet server is included in Table 1.

3.2 Server and Real-Time Control Software

For deterministic real-time control using Windows NT, Hyperkernel has been used. CPU time and memory resources are partitioned between Windows NT and Hyperkernel. Communication between the programs in the two partitions occurs via shared memory, as shown in Fig 5. Hyperkernel has its own scheduler and its own internal kernel. In practice, the CPU time allotted for Windows NT and Hyperkernel is proportioned into alternating 250 microsecond segments. Because of this duality, two sets of code were written in C++. This allows the real time control of the experiment to proceed without the uncertain delays of the Windows NT scheduled tasks.

The server code written for Windows NT handles the socket connection with the client and is responsible for starting the Hyperkernel code. The Hyperkernel code, modeled after code written by CAMotion Inc., is responsible for the real-time control, and contains a main thread, an Interrupt Service Routine (ISR), and a thread used for input and output. Both Windows NT and Hyperkernel programs are run on the computer that acts as the Internet server for the client applet. Using Hyperkernel APIs, the ISR signals the input/output thread to send and receive the next data values. Data received from the client, such as the desired input type and gain values, is passed from Windows NT to Hyperkernel through shared memory. An illustration of this concept is in Fig 5. Code has been added to ensure the integrity of various structures passed via shared memory.

As the experiments change from week to week, similar GUI's with different experimental options will be provided to the student. This will eliminate the risk of students unintentionally running an experiment for which the hardware has not been configured. Other safety issues may include students inadvertently selecting inputs that could potentially damage the hardware or surrounding objects. For this reason, the server will contain code that inspects the inputs received and stops the experiment if it is not safe.

4. EXPERIMENTATION

The following experiments are planned.

- System introduction
- System identification, force response
- System identification, position response with proportional feedback control
- PID control
- Trajectory planning
- Successive loop closure

These experiments illustrate to the students several concepts of system dynamics and control, such as natural frequencies, damping ratios, steady state error, stability and instability, and the effects of feedback. Other aspects specific to hydraulic systems will also be presented such as valve limits (saturation), drive backlash, actuator compliance, and actuator stiction.

5. CONCLUSION

The Virtual Access Laboratory provides many benefits to students as well as faculty. Such a laboratory gives students insight into hydraulics and mechatronics and assists them in learning the basics of system modeling and control. The time burden for faculty and the financial burden for the institution are reduced at the same time. The use of Java applets will provide students with an interface that has a familiar look and feel while they learn unfamiliar concepts. A camera provides students with visual data and the realization that they are working on an experiment rather than a simulation.

REFERENCES

1. Davidson, I.J., *Tele-operation of a manipulator using the Internet*, M.S. thesis, Georgia Institute of Technology, Atlanta, Georgia (1999).

2. Thompson Learning, (2000). http://www.webct.com.

Figure 1

Fig 1. Schematic of Hydraulic Manipulator

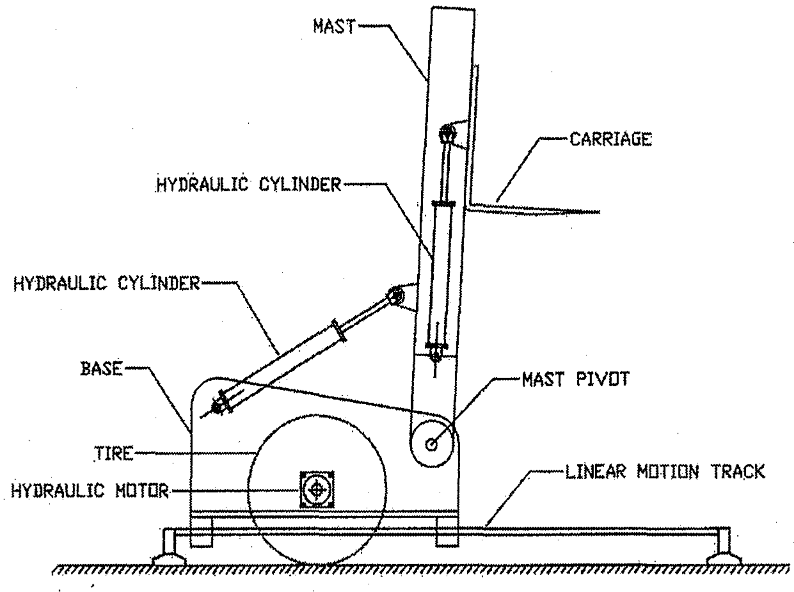

Figure 2

Fig 2. Rendering of Hydraulic Manipulator

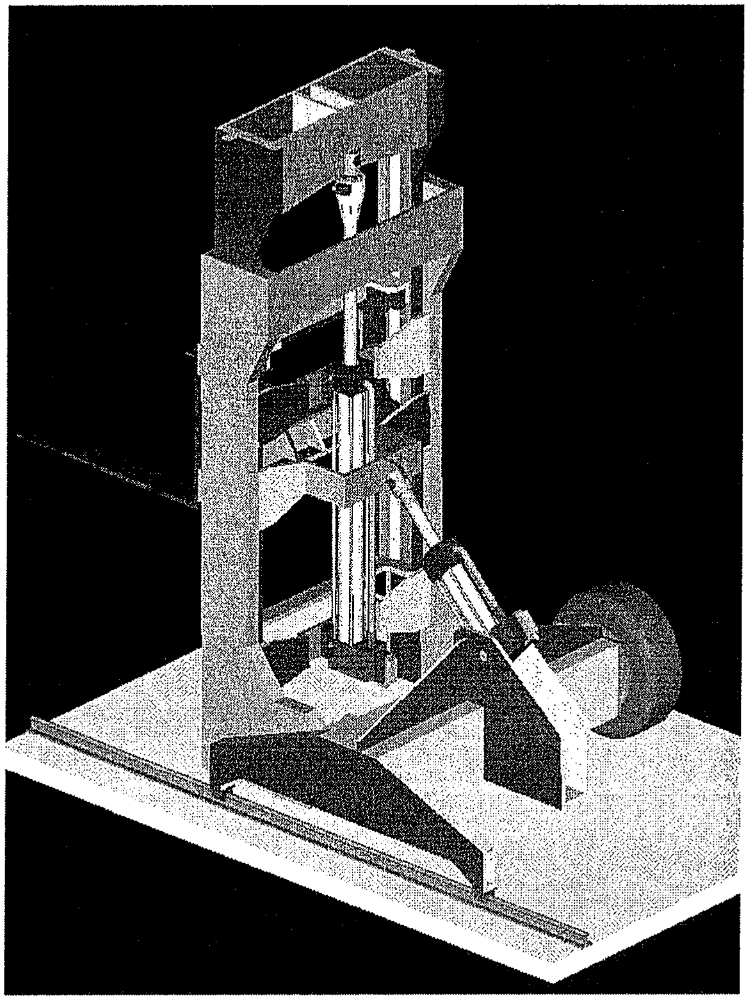

Figure 3

Fig 3. Hydraulic System Schematic

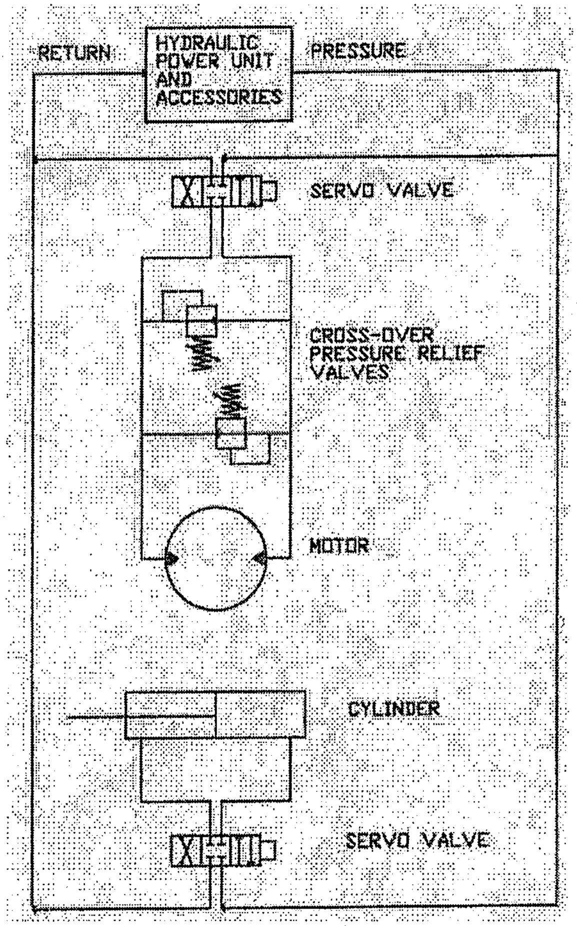

Figure 4

Fig 4. Schematic of Input/Output Signals

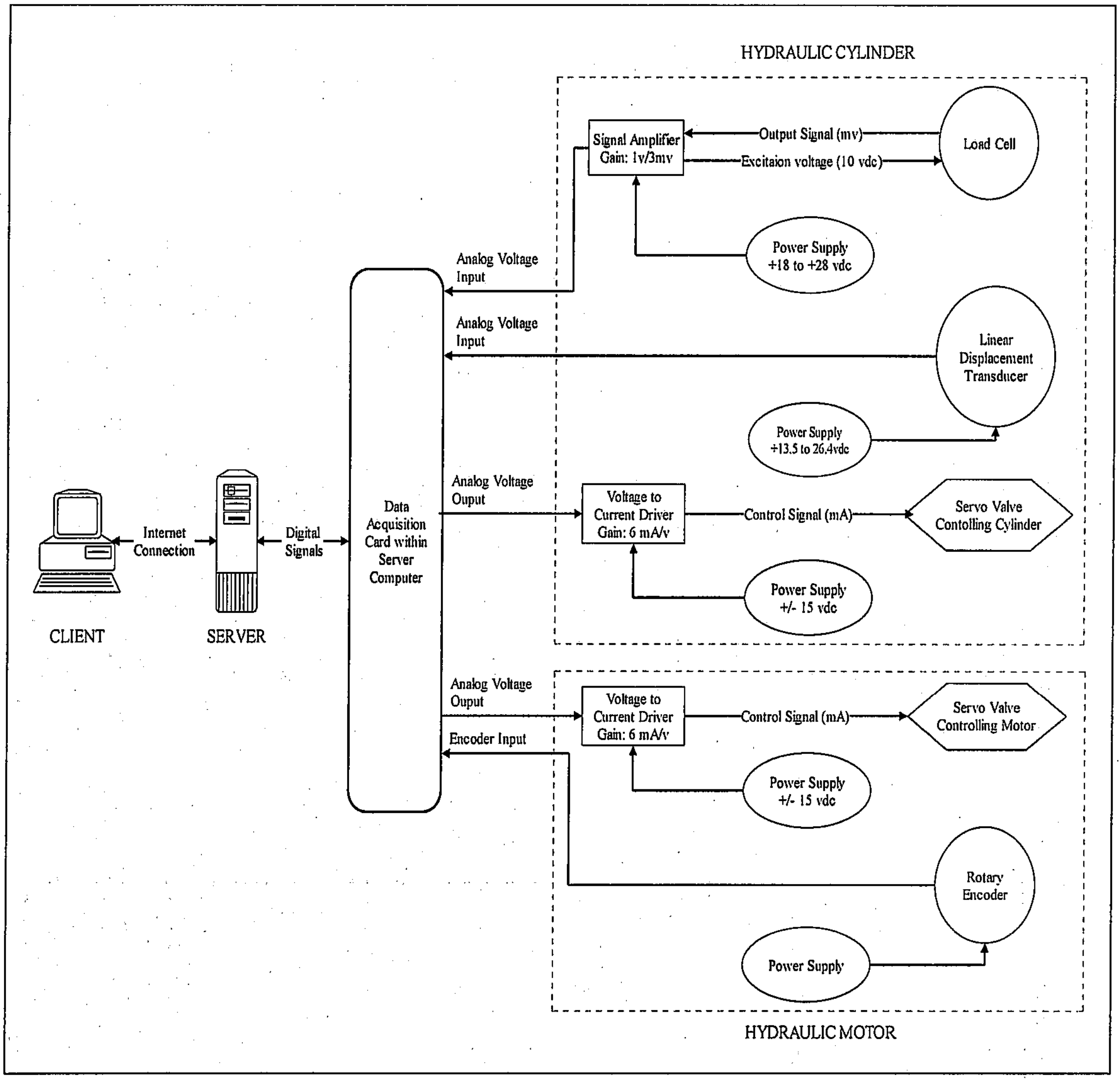

Table 1.

Table 1. Steps Involved in Typical Experiment

Browser/WebCT Server	Browser/VAL Server
1. Enter WebCT	
2. Sign up for access time slot	
3. Log off WebCT	
4. Manual grouping of students for access times	
5. Log on to WebCT	
6. Access instruction page	
Beginning of release time for access	
7. Access experiment page on VAL server	
	8. Java applet is transferred to browser
	9. Applet establishes socket connection
	10. Student sets up experiment through applet
	11. Student runs experiment
	12. Student views and judges results. Return to 10 if needed.
	13. Student saves results for post processing
	14. Close socket connection
	15. Return to WebCT
End of release time for access	
16. Perform other WebCT functions if desired	
17. Log off WebCT	

Figure 5.

Fig 5. Windows NT and Hyperkernel Relationship